An Introduction to Oscillators... and a Blast from the Past

If you've got a radio—any radio—and you want to know "how it works," then you need to start by understanding oscillators. We've got you covered—PLUS Dave's got a homebrew project for you: a 1930s-style 6-meter AM transceiver!

Our quest for electronic knowledge and pursuit of related quick-brew fun projects continues this month, and we have some very interesting info to share with you. In the spotlight this time are *self-excited oscillators*, those main "building blocks" found in communications equipment of all types. Without these frequency determining and controlling circuits, modern radio and television could not exist. We'd all be transmitting and receiving in the same general frequency range or around the same wavelength—total confusion for sure.

Also this month, we'll take a heart-warming look back in time at one of the very first homebrewable (and easy-to-duplicate) VHF transceivers; a rig from, believe it or not, 1936. That's right. Two decades before fancy transceivers appeared on the scene, hopped-up oscillator varieties were in use on VHF bands. Surprise! We have some exciting ground to cover, so let's get rolling!

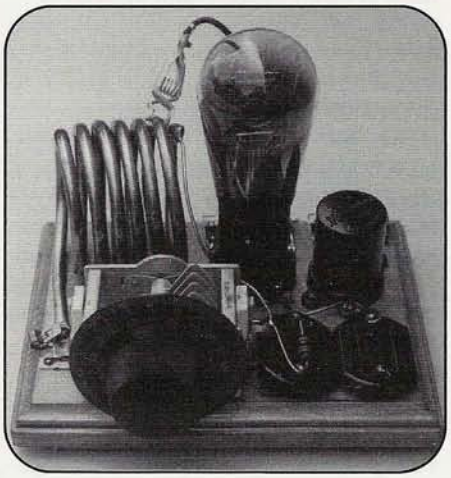

Photo A. This modern-day replica of a 1930-style transmitter uses a type 45 tube in a basic Hartley oscillator circuit and pumps out a healthy 5-watt signal on any frequency its tuned circuit covers. When powered from a well-filtered and regulated power supply, it emits a beautiful sounding signal on today's bands.

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Oscillators Simplified

Since we're introducing a new topic for discussion, let's begin with a quick "applicable to all" explanation of what oscillators are and what they do. We can then expand our studies into more advanced types "down the line."

Oscillators are used to generate various RF (radio frequency), IF (intermediate frequency), and AF (audio frequency) signals employed in all types of communications gear, and they can be separated into two rather broad categories: self-excited and crystal-controlled. Both types of oscillators typically produce a low level signal on a desired frequency and rely on a following amplifier or buffer stage for increasing output power.

Self-excited oscillators are the easiest to homebrew from "junkbox" parts and are the most frequency-agile (they can be assembled to tune any frequency range), but crystal-controlled types are more accurate and stable for "stay put" operation. An easily recognized example of a crystal-controlled oscillator is the local oscillator stage in a modern transceiver, or a little "barebones" QRP transmitter. A comparable example of a self-excited oscillator is the CW sidetone stage in a multimode transceiver or a 1930s-style transmitter like the one shown in Photo A.

"Swinging" Oscillators

Oscillators typically generate a frequency by using a tube or transistor (or equivalent device within an integrated circuit, or IC) to electrically activate or energize a tuned circuit. This "push," or activation, then causes the tuned circuit's coil and capacitor to exchange their acquired electrical energy back and forth at a rate, or frequency, determined by the coil's inductance and the capacitor's capacitance.

In many ways, watching a parent push a youngster in a swing is a convenient way to visualize an oscillator's action. How so? The parent briefly pushes the swing, then pauses or rests while the swing goes through a complete back-and-forth cycle. Each time the swing returns to its starting

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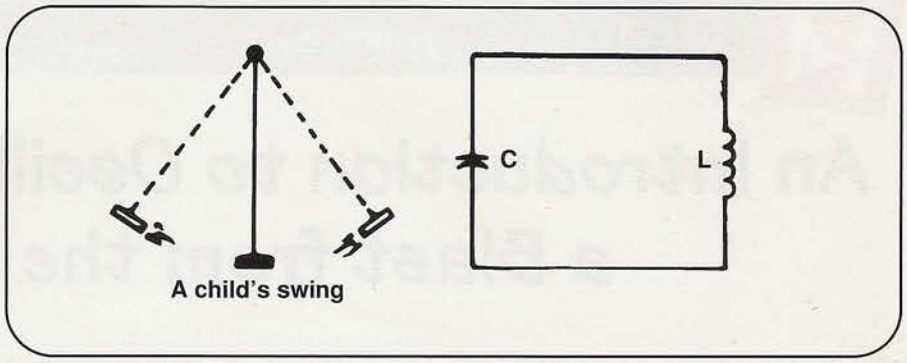

Figure 1. The back-and-forth movement of a child's swing is a good analogy for how an oscillator generates a signal on a specific frequency by exchanging energy between its tuned circuit's coil and capacitor. Discussion in text.

point, the parent gives it another brief push and the cycle repeats. Now compare one side of the swing's arc of travel to a tuned circuit's capacitance and the other side to its inductance (Figure 1). Also imagine the length of time or speed at which the swing goes through each full cycle as the tuned circuit's frequency. Notice, too, that a "balanced condition" of equal travel on each side of the swing's arc plus an accurately timed and repetitive "push" are necessary for sustained smooth action. The equal travel is akin to equal capacitive and inductive *reactances* in an oscillator's tuned circuit, and the timed "push" is comparable to using grid or base leak bias (more on this later) with the proper time constant for a selected frequency range.

Still with me? OK, now let's "bring everything together" with an overview of how three classic oscillator circuits actually work.

Lights, Camera, Oscillation!

Heading up our discussion of self-excited oscillators in action is the ever popular *Armstrong* oscillator shown in Figure 2. A tube or a transistor could have been used as the active device in this circuit, but I chose a tube because it just seemed like a "natural" for this timeless classic. Let's step through its cycle of operation.

Like all self-excited oscillators, the Armstrong uses *grid leak bias*. As a result, no bias is present at turn-on and near-full current flows from ground, or the power supply's negative terminal, to the tube's cathode, on to its plate, and back to the power supply's positive terminal. This change from zero to near-full plate current causes "tickler" winding L2 to produce a continuously expanding electromagnetic field. Since L2 is in close proximity to L1 (usually it's comprised of insulated wire and wound on top of L1), it begins to induce voltage into L1. This voltage increases as L1's electromagnetic field expands, so the *increase* or *change* (from a fixed value of zero to a more positive voltage) "looks like" AC to the grid capacitor C2, and thus goes right through it.

This positive-going cycle of voltage is then felt on the tube's grid and further supports current flow until the tube reaches saturation and plate current becomes steady (rather than increasing to maximum). When plate current becomes a steady value, tickler winding L2 no longer produces an expanding electromagnetic field and thus stops inductively coupling voltage into L1. Simultaneously, the tube's grid (which previously was positive) begins pulling current *from* the main electron stream within the tube.

This current, in turn, charges grid leak capacitor C2 with an *opposite polarity* voltage (minus toward grid). This negative-going voltage quickly increases to the point where it cuts off current flow in the tube (because the tube's grid now feels a negative voltage on it). The tube then gets a short rest (a gasp!) while the biasing charge in grid capacitor C2 "leaks down to zero" through its shunting resistor, R1. Meanwhile, voltage induced into L1 by L2 charges C1. Ah, but immediately after C1 charges, it "realizes" there's a coil shorting its terminals and it discharges (the opposite way) back through L2. Bingo: oscillation is produced at the resonant frequency of L1 and C1. When voltage across C2 leaks down low enough, the tube again conducts. Again, this changing voltage inductively couples into L1, again C2 charges and cuts off plate current flow at saturation, and the cycle repeats. A separate pickup coil usually couples the signal out of an Armstrong oscillator.

Now would you like to see the Armstrong circuit work with a transistor

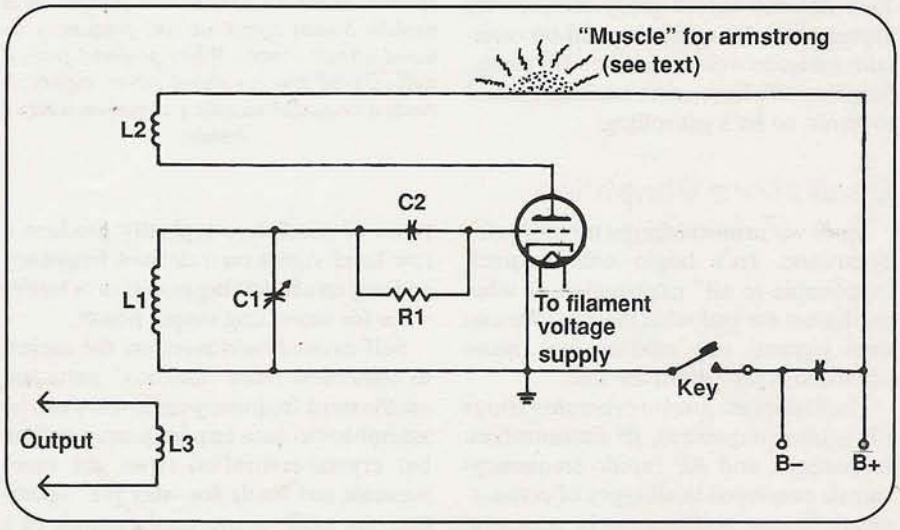

Figure 2. The circuit diagram of the ever-popular Armstrong oscillator is fairly easy to understand and thus makes a good starting point for our "How It Works" discussion in text. Note that I added a "muscle" to the circuit's associated "arm" for easy recognition.

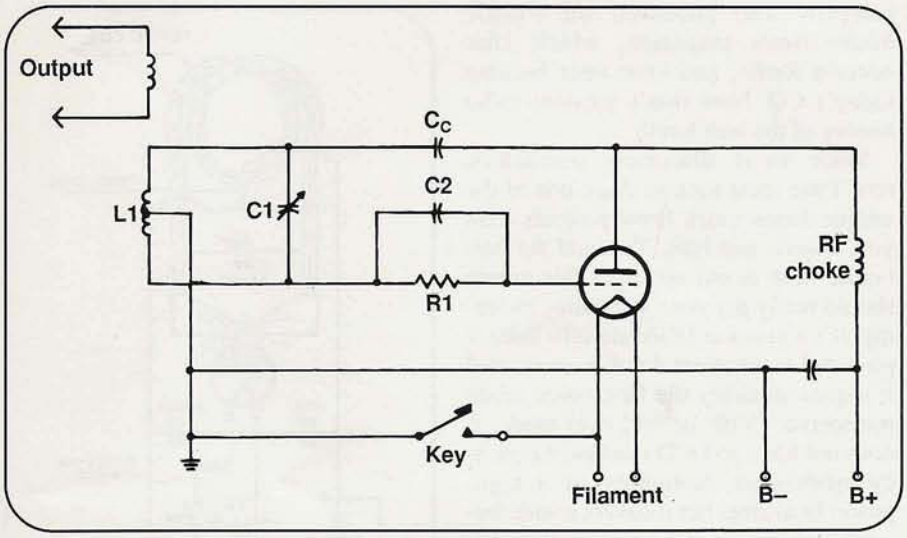

Figure 3. Circuit diagram of the famous Hartley oscillator. Operation of this circuit is similar to the Armstrong, except a tapped coil is used in lieu of separate tickler winding. Think "tapped coil, measured in Henrys, H-Henry, H-Hartley," and it's easy to remember. The circuit shown also applies to classic transmitter in Photo A.

rather than a tube? Just change the tube's symbol to an NPN transistor with the emitter in place of the cathode, the base in place of the grid, and the collector in place of the plate, and visualize using a lower voltage—or reverse polarities and use a PNP transistor. Essentially that's how an oscillator works. We could have delved into more technical complexities, phase relations, etc., but let's keep this study lighthearted rather than hard nosed.

Hartley-Davidson?

Two additional and always-popular types of self-excited oscillators are the famous *Hartley* and *Tuned Grid-Tuned Plate* versions shown in Figures 3 and 4. Both of these circuits work on the same principle of feeding back energy from their plate (or collector) to produce and sustain oscillation in their tuned circuit. How that energy is fed back, however, is what makes the two circuits different.

In the *Hartley* (Figure 3), the tap on L1 causes it to act like an autotransformer. When plate current flows, a brief pulse goes through Cc and is coupled into the above-tap section. This, in turn, induces oscillator-sustaining voltage into the below-tap section. Again, as in the Armstrong, this initial rise of positive voltage causes the tube to reach saturation, draw grid current, charge C2, and cut off plate current flow. From that point, operation of the Hartley and

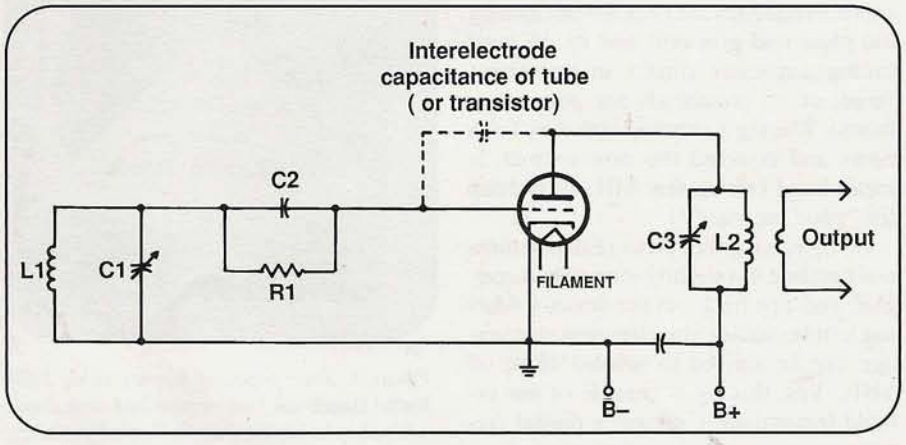

Figure .4 Circuit diagram of the tuned grid-tuned plate oscillator. This design depends on the interelectrode capacity of the tube (or transistor) plus proximity of coils for oscillator-sustaining feedback. The circuit is also a bit more stable than other self-excited types.

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Operating Notes

Should you choose to operate this radio with an antenna, be sure—as noted in the text—to check with a frequency counter or well-calibrated modern transceiver to assure in-band operation (also check for harmonics and other spurious emissions). In addition, you should avoid the low end of the 6-meter phone band so you don't interfere with SSB contacts. The unofficial 6-meter AM calling frequency is 50.400 MHz, so this should be a good place to look for other AM enthusiasts once you're sure the rig is working well (do your testing off of the calling frequency). If the band opens up, you may find you have a good deal of company...and a good deal of fun!

Armstrong oscillators is basically the same. That is, voltage exchanged between L1 and C1 produces oscillations at a selected frequency and a separate pick-up coil couples the signal to a following stage or antenna.

One final note bears mentioning. The Hartley diagram shown in Figure 3 corresponds to my 1930s replica transmitter shown in Photo A, which employs a directly heated tube like the type we discussed last month. Do you remember the difference between indirectly and directly heated tubes? I occasionally use this little rig on the air today, and it is a treat.

In the *tuned grid-tuned plate* circuit (Figure 4), the grid coil receives its oscillation-sustaining "kicks" or voltage pulses through capacity coupling from the plate to the grid *within* the tube. In many TGTP circuits, the grid and plate coils are also positioned near each other to enhance feedback and ensure stable oscillator.

That's enough theory for this time. Now let's focus on a fun oscillator-related project!

A Blast from the Past

A few months ago, Paul Messer, KB4TTT, gave me a 1936 edition of the famous Frank C. Jones *Radio Handbook* (Photo B), and I've had a ball homebrewing some classic rigs from this legendary publication. I say "legendary" because the book was written by a "biggie" of the time and published by the Pacific Radio Publishing Company. This company also published the *Pacific Radio News* magazine, which later became *Radio*, and even later became today's *CQ*. Now that's amateur radio history of the best kind!

Since we're discussing oscillators, now's the ideal time to share one of the unique Jones quick-brew projects with you, friends and fans. Yes, and the particular item in our spotlight this month should really get your adrenaline pumping. It's a genuine 1936 one-tube battery powered transceiver for 6 meters, and it's quite possibly the first voice mode transceiver (VHF or HF) ever made. It does not have an LCD readout, frequency synthesizer, memories, or a high-power final amp, but it covers a wide frequency range (on receive and transmit!), plus it works AM (and even FM when battery juice is low!).

In other words, it's a "wild child" by modern standards and requires some conscientious and careful handling if you use it with an outdoor antenna today. Alternately, you can just assemble it as an historical display item or use it without an external antenna for around-the-shack demos. Or you might build a pair of them for fun use within a two or three block area (without antennas). Hopefully, I'm not creating a monster here, and you understand this little tyke is about as crude as they come. A pile of notes must now be squeezed into a couple of paragraphs, so read close and digest the info as we continue.

The circuit diagram and physical details of this mini-transceiver are shown in Figures 5, 6, and 7. It uses a genuine 1936 type 19 tube, which functions as a grid bias-modulated tuned grid-tuned plate oscillator on transmit and doubles as a super-regenerative circuit on receive. Frequency range is determined by the plate and grid coil and its 15 mmf tuning capacitor (that's micro-microfarad, or 15 picofarads for you newer hams). The rig's original coil was 1-5/6 turns and covered the now-extinct 5-meter band (with a few MHz of overlap for "good measure"!).

By increasing the coil to a full two turns and bending its (slightly longer than original) end tips back out for direct-soldering to tube socket pins, frequency coverage can be shifted to around 48 to 60 MHz. Yes, this rig is capable of out-of-band transmission, so use a digital frequency counter or a modern transceiver to initially check/set the rig to an in-band frequency—and recheck it regularly. Frequency stability, such as is possible

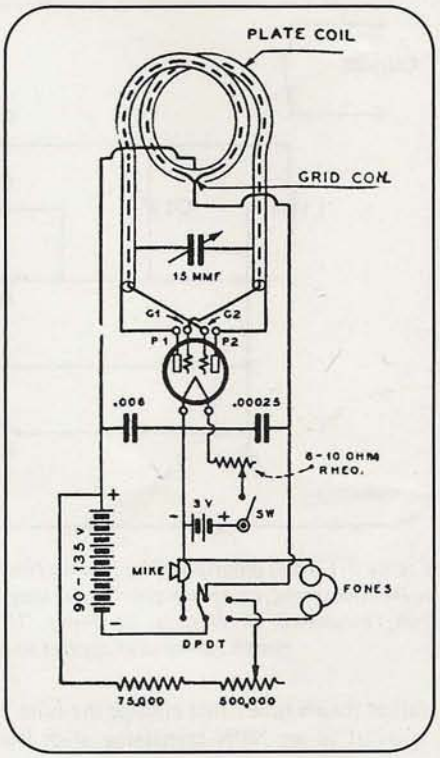

Figure 5. Circuit diagram of the one-tube 1936 transceiver. The little rig was used and proven by Allied Radio Corporation in its original "Knight" transceiver built by youngsters nationwide, then revised slightly by Jones and featured in his Handbook. Quickly—what type oscillator is this, friends?

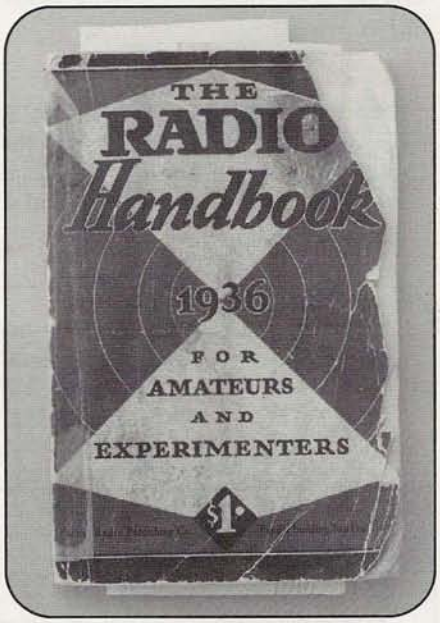

Photo B. True pages of history! This 1936 Radio Handbook *was written by Frank Jones and published by the Pacific Radio Publishing Company, which was a forerunner of today's* CQ *and* CQ VHF. *One of its featured projects was the one-tube, battery-powered transceiver revisited in this month's column.*

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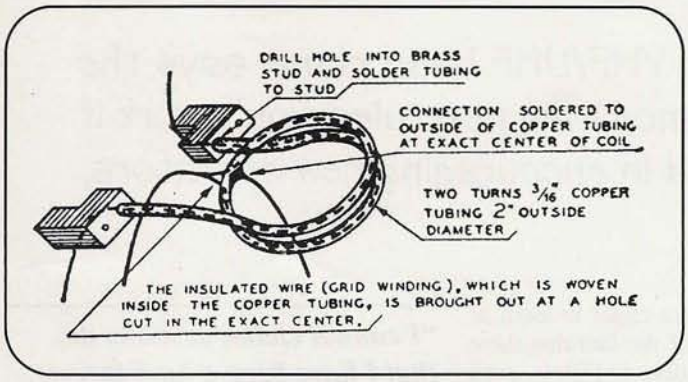
DRILL HOLE INTO BRASS STUD AND SOLDER TUBING TO STUD
CONNECTION SOLDERED TO OUTSIDE OF COPPER TUBING AT EXACT CENTER OF COIL
TWO TURNS 3/16" COPPER TUBING 2" OUTSIDE DIAMETER
THE INSULATED WIRE (GRID WINDING), WHICH IS WOVEN INSIDE THE COPPER TUBING, IS BROUGHT OUT AT A HOLE CUT IN THE EXACT CENTER.

Figure 6. Assembly details of the plate coil with the grid coil inside it. Details in text.

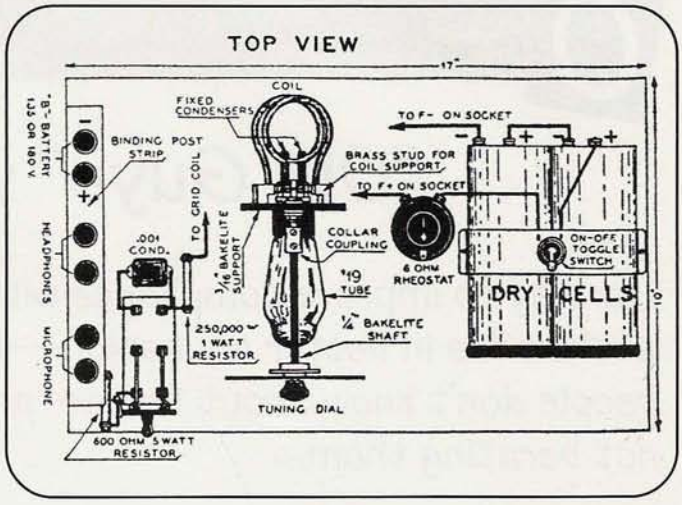

Figure 7. Layout of the 1936 transceiver as sketched in Jones's Handbook. *Although originally built open-air style on a 10- by 17-inch pine board, this little gem could be condensed to fit into a file box with the tube extending out the side or top. Don't look too closely or you'll notice Jones's habit of substituting off-the-wall values in components. Whew!*

for a 1936 self-excited rig, is achieved by "unity coupling." That is, the grid coil is placed—are you ready for this—*inside* the plate coil (see Figure 5 and detail in Figure 6). Big time radio for sure! Whew! Here are the amazing details:

The plate coil consists of 3/16- or 1/4-inch soft copper tubing wound two full turns with an O.D. (outside diameter) of 2 inches. Leave approximately 1-1/2 inch leads on each end of the coil for direct connection to the tube socket's pins or brass mounting studs screwed to socket pins (you make 'em). Cut a 1/2-inch wide slot in the lower area of the tubing at the coil's center and thread a well-insulated length of rubber- or plastic-coated wire through each side of the tubing. Allow their ends to extend about an inch out of the copper coil's ends for trimming, stripping, and connecting to the tube socket's grid pins. Connect the middle sections together to produce a center tap. Solder a separate wire directly to the copper coil's center for connection of plate voltage (in upper area, opposite the slot for grid coil wires, as shown in Figure 6).

Check your assembled coil with an ohmmeter to ensure grid and plate windings are insulated from each other. When installing the coil, cross its grid leads over to opposite terminals on the tube socket. This helps keep coil taps clear of other socket pins. Mount the tuning condenser (what they called capacitors in the 1930s) near the tube socket so its leads are also 1 inch to 1-1/2 inches long. Add an insulated shaft extension for minimizing hand capacity when adjusting this (frequency-setting) condenser. The tube is mounted horizontally for minimum lead length.

This rig's microphone uses a single button carbon-type element—just like those used in regular (wired) telephones. The earphone is a high impedance type (also as used in telephones). Don't cannibalize your home phone for these items, however; substitutes are plentiful at hamfest fleamarkets or from such suppliers as Antique Electronic Supply (6221 S. Maple Avenue, Tempe, AZ 85283; phone: 602-820-5411).

We're now overflowing space, so here are some quick closing notes. Two "C" cell batteries work fine for the tube's filament supply. Ten to 15 series-connected 9-volt batteries will make a handy plate supply. You might even cover them with a homemade Burgess battery wrapper for authenticity.

Testing and Operation

When operating properly, the rig will draw 5 or 6 milliamps (mA), and its earphone will emit a light hiss on receive. Plate current will increase to 30 to 50 mA without an antenna connected or 15 to 20 mA with an antenna on transmit. A 3- or 6-volt flashlight bulb connected to a two-turn pickup coil placed beside (or inside) the plate coil should illuminate well on transmit—just like old times. A single 4-1/2-foot wire, alligator clip-lead-connected to the copper coil near its center tap, makes a good antenna. Experiment with that tap point. When correct, the receiver will still hiss over its full tuning range.

Have fun dinking with this experimental rig (but not on local repeaters and not on the SSB calling frequency!) and stay tuned for more theory 'n practice fun next month. 73, —Dave, K4TWJ

A Note on Mail for Dave

Questions and comments for Dave Ingram, K4TWJ, are welcome and appreciated. Due to the large volume of correspondence Dave receives, most e-mail will be answered, on a space-available basis, in his column. This way, everyone benefits from shared knowledge. If you prefer a more personal reply, send a brief letter (with space provided for replies/answers), along with a self-addressed stamped envelope (SASE), to Dave Ingram, K4TWJ, 4941 Scenic View Dr., Birmingham, AL 35210. Or, if you're active on HF as well as VHF, listen for Dave on Sundays between 2200 and 2230 UTC around 14.200 MHz (±QRM), or weeknights on 30 meters.